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**FEASIBILITY OF GRANULAR,
ACTIVATED-CARBON ADSORPTION
FOR WASTE-WATER RENOVATION. 2.**

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**FEASIBILITY OF GRANULAR,
ACTIVATED-CARBON ADSORPTION
FOR WASTE-WATER RENOVATION. 2.**

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for

**The Advanced Waste Treatment Research Program
Basic and Applied Sciences Branch
Robert A. Taft Sanitary Engineering Center**

A report submitted in fulfillment of contracts between the Public Health Service and Pittsburgh Chemical Company and its successor the Pittsburgh Activated Carbon Company. The report presents results of all the investigative efforts of Contract No. PH 86-62-15 for the period July 3, 1962, to July 1, 1963, and parts of the work accomplished under Contract No. PH 86-63-243 for the period June 26, 1963 to June 30, 1964. Submitted in September 1963 and November 1964, respectively.

**U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control**

October 1965

The ENVIRONMENTAL HEALTH SERIES of reports was established to report the results of scientific and engineering studies of man's environment: The community, whether urban, suburban, or rural, where he lives, works, and plays; the air, water, and earth he uses and re-uses; and the wastes he produces and must dispose of in a way that preserves these natural resources. This SERIES of reports provides for professional users a central source of information on the intramural research activities of Divisions and Centers within the Public Health Service, and on their cooperative activities with State and local agencies, research institutions, and industrial organizations. The general subject area of each report is indicated by the two letters that appear in the publication number; the indicators are

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ADVANCED WASTE TREATMENT RESEARCH PROGRAM

The Advanced Waste Treatment Research Program of the Public Health Service has two ultimate goals: One is to help abate our Nation's growing water pollution problems, and the other, more startling in concept, is to renovate waste water for direct and deliberate re-use.

Conventional water and waste treatment practices have little or no effect on many simple inorganic salts and permit an ever-increasing number and amount of highly complex, synthetic organic wastes to contaminate drinking water supplies. If we are to protect these water supplies for the future, it is mandatory that new technologies for water and waste treatment be developed.

Advanced Waste Treatment may be looked upon as a two-step process: (1) Separating concentrated contaminants from the purified water "product," and (2) disposing of the concentrated contaminants in a way that will render them forever innocuous. This "permanent disposal" of separated wastes is essential so that useable surface or ground waters will not be contaminated and so that the same contaminants need not be removed again and again from water supplies.

In one step, then, advanced waste treatment, i.e., water renovation, could alleviate both water pollution and water supply problems — problems of increasing concern both in this country and in the rest of the world. The importance of advanced waste treatment was recognized by Congress in its 1961 amendments to the Federal Water Pollution Control Act (Public Law 87-88). This act directs the Secretary of Health, Education, and Welfare ". . . to develop and demonstrate practicable means of treating municipal sewage and other water-borne wastes to remove the maximum possible amounts of physical, chemical, and biological pollutants in order to restore and maintain the maximum amount of the Nation's water at a quality suitable for re-use."

It is too early to predict accurately the cost of advanced waste treatment technology, but the need is inevitable. Because of population increase and industrial expansion, we are approaching the time when our rivers and streams will no longer be able to assimilate our wastes and when there will be no more developable supplies of fresh water. Whatever the cost of this technology, one thing is certain — it must be the very lowest science and engineering can achieve. Anything more will impose an inexcusable, perhaps intolerable burden on our country's economic growth and on its ability to compete in tomorrow's world.

Pittsburgh Activated Carbon Company (formerly Pittsburgh Chemical Company - Activated Carbon Division) is a subsidiary of Pittsburgh Coke & Chemical Company. The Company, one of seven manufacturers of activated carbon in the United States, produces activated carbon for the purification of both liquids and gases and has been particularly active in the manufacture of carbon for the purification of water. This Company has generally specialized in granular carbon that can be reactivated and re-used many times. Mr. Joyce and Mr. Sukenik are supervisor and technologist, respectively, in activated carbon research, Research and Development Department.

The authors are indebted to the Pleasant Hills Sewage Treatment Authority for permission to conduct the column tests at their plant. Particularly, thanks are due to Mr. Richard S. Dodds, Plant Superintendent, and his staff for their help and cooperation during the tests and their performance of the BOD determinations. Appreciation is also extended to Miss Jayne Schmitt and Mrs. Frances Brunner for all of the other analyses.

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ABSTRACT

Granular, activated carbon in packed-bed column contactors 20 feet deep and operated at a flow rate of 4 gpm per square foot reduced the COD to an average value of 18.5 ppm. The removal was not significantly different from the removal obtained when operating the same column at 10 gpm per square foot. After 4 months of operation, the first quarter of the column length was still accomplishing a significant part of the overall removal. Typical adsorption isotherms for type SGL carbon for COD indicated capacities of approximately 35 percent by weight. The cyclic saturation and regeneration of activated carbon through 16 cycles had an average carbon loss of 4.6 percent per cycle. A practical adsorption capacity was maintained for the regenerated carbon even though reactivation conditions for carbon spent on municipal waste-water treatment purification have not been explored and optimized. Flocculation with alum of secondary effluent prior to carbon adsorption increased the adsorption capacity of the carbon and resulted in much lower final levels of COD than the levels obtained with unflocculated effluent.

FEASIBILITY OF GRANULAR, ACTIVATED-CARBON ADSORPTION FOR WASTE-WATER RENOVATION. 2.

Introduction

In the first interim report on this contract (AWTR-10, PHS Publication No. 999-WP-12)¹ it was shown that treatment of secondary wastewater effluent from an activated-sludge process with granular, activated carbon in a column process reduced the COD content to concentrations between 12 and 20 ppm. The ABS removal was essentially complete. The feasibility of thermally reactivating the spent carbon for re-use was, moreover, demonstrated. It was estimated that for this degree of treatment less than 1 pound of carbon would be regenerated per 1,000 gallons of secondary effluent treated.

The current study was initiated primarily to determine if an increased contact time in the carbon bed, effected by a reduction in flow rate, would improve the degree of COD removal. Secondly, cyclic re-activation tests were conducted in which the carbon was alternately exhausted with secondary effluent to the degree expected in practice and thermally reactivated to determine the actual operating capacity of the carbon. Finally, a preliminary study was made to determine the feasibility of treating primary effluent with granular carbon in a column process.

SUMMARY

Treatment of secondary waste-water effluent, averaging 72 ppm COD and 3.8 ppm ABS, in a bed of granular, activated carbon 20 feet deep, at a flow rate of 4 gpm per square foot, reduced the COD to an average value of 18.5 ppm and the ABS to well below 0.5 ppm. The amount of carbon that would be regenerated in a countercurrent system to accomplish this degree of purification is estimated to be approximately 0.75 pound per 1,000 gallons of secondary effluent treated.

The residual COD content of 18.5 ppm obtained in these tests is obviously no better than the 12 to 20 ppm concentrations obtained previously at a flow rate of 10 gpm per square foot at the same bed depth. Filtration tests with millipore filters showed that the residual COD was not due to suspended solids. The possibility of its being due to colloidal material or difficultly adsorbable organics has not been precluded.

Granular, activated carbon was alternately exhausted, to the degree that might be expected in practice by the column treatment of secondary effluent, and thermally reactivated. A buildup of water-insoluble, acid-soluble ash occurred. The adsorptive properties of the carbon, as measured by standard activity tests, were not seriously impaired except for the iodine number, which was significantly reduced. After the 10th and 15th exhaustion-reativation cycles, the regenerated carbon was compared to virgin carbon in parallel contacting columns. The virgin carbon performed appreciably better than the regenerated in removal of COD, ABS, etc. from secondary effluent. During the test, regeneration to restore the apparent density to that of virgin carbon was practiced. It is postulated that regeneration to the same iodine number will better restore adsorption properties.

The carbon loss in the laboratory-scale rotating furnace used for regeneration averaged 4.6 percent.

Flocculation with alum and settling of the secondary effluent prior to carbon adsorption increased the adsorption capacity of the carbon and resulted in much lower levels of COD than the levels obtained with unflocculated effluent.

In a single test, primary waste-water effluent was passed through a sand filter and treated in a granular carbon bed 20 feet deep. The average concentrations of the contaminants in the sand-filtered primary effluent were 5.6 ppm ABS, 236 ppm COD, and 154 ppm BOD. The carbon treatment reduced these to average values of 0.2 ppm ABS, 91 ppm COD, and 67 ppm BOD. During the test period the final effluent from the activated-sludge system at the waste-water treatment plant had an average BOD content of 18 ppm. Millipore filtration tests showed that a considerable fraction of the residual COD in the effluent from the carbon column could be accounted for by suspended solids that penetrated the carbon bed. These were not effectively removed by the sand filter and penetrated the carbon bed to such an extent that rapid increases in pressure drop occurred necessitating frequent washing of the carbon and making accurate control of the flow rate impossible. The mechanical problems associated with the suspended solids, and the unsatisfactory BOD and COD reductions obtained led to the conclusion that carbon treatment of primary effluent by this system was not feasible.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH AND INVESTIGATIONS

It is recommended that a series of bench scale tests be conducted to obtain the information necessary for reasonably accurate estimates of the cost of treating secondary effluent with granular, regenerable, activated carbon. Specifically, the following experimental program is recommended:

1. Determination of whether or not the practical capacity of a layer of carbon, in the treatment of unfiltered secondary effluent, would be utilized before solids deposition effected prohibitive pressure drop. This information is necessary to determine if provision must be made for backwashing the carbon or using an alternative cleaning procedure.
2. It is anticipated that adsorbers of large cross-sectional area will be used for the treatment of secondary effluent and that, if moving or "slug" type beds are used, several discharge points will be necessary. It is recommended that the effect of layer depth to diameter ratio on the efficiency with which a layer of carbon can be withdrawn from a conical section through a single discharge point be investigated to determine the area that can be serviced by a single discharge point.
3. It is recommended that the economics of treating secondary effluent with granular carbon be thoroughly evaluated to determine optimized design for minimizing investment and operating costs and to predict those costs with reasonable accuracy.

EXPERIMENTAL MODE

Isotherm Tests

ABS and COD isotherms were determined on several samples of secondary and primary waste-water effluent from the Pleasant Hills Treatment Plant by using Pittsburgh Types SGL and MWT* granular, activated carbons. The apparatus and procedures used have been described previously.¹

* Pittsburgh Types SGL and MWT carbons were referred to as carbons B and C, respectively, in the First Interim Report, PHS publication No. 999-WP-12, 1964.

Column Tests

All the column tests were conducted at the Pleasant Hills Treatment Plant whose design and operation were outlined previously.¹ Plant-operating data for the test periods are summarized in Table 1. Pittsburgh Type SGL carbon was used for all the tests.

Table 1. AVERAGE VALUES OF FLOW RATE, BOD, AND SUSPENDED SOLIDS AT THE PLEASANT HILLS PLANT DURING THE TEST PERIODS

Dates	Effluent used for column test	Flow mgd	BOD, ppm			Suspended solids, ppm		
			Raw	Primary	Secondary	Raw	Primary	Secondary
7/30 to 12/1, 1962	Secondary	1.78	212	122	11	230	83	21
12/19/62 to 1/14/63	Primary	2.24	201	125	16	218	108	28

COLUMN TESTS ON SECONDARY EFFLUENT AT 4 GALLONS PER MINUTE PER SQUARE FOOT

The column system described previously was modified by subdividing the first 5 feet of bed depth into a series of shallower beds so that effluent samples could be collected at intermediate bed depths of 4, 8, 16, and 30 inches. This was accomplished by flanging four straight 2-inch-i.d. Pyrex pipe sections and two 2- x 3/8-inch Pyrex pipe reducers together to form a single 6-foot assembly, illustrated in Figure 1. Pieces of 50-mesh stainless steel screen were held in the flanges by means of rubber gaskets and served as bed supports. Pyrex pipe "tees" were sealed to the three lower straight sections near the upper ends. Pressure gages were attached to the upper arm of the "tees" by means of pressure fittings, and the lower arms were fitted with rubber tubing and pinch clamps to serve as sampling ports.

The modified column assembly held from top to bottom, two 4-, one 8-, and one 14-inch bed. It was installed prior to the existing four-column train. The second column in the system was charged with a 30-inch bed of carbon and the remaining three with 5-foot beds to give a total bed depth of 20 feet.

The Pyrex pipe reducers at the bottom of each column section were painted black and the straight sections were wrapped with aluminum foil in an effort to eliminate light and prevent the algae growth encountered in the previous work.

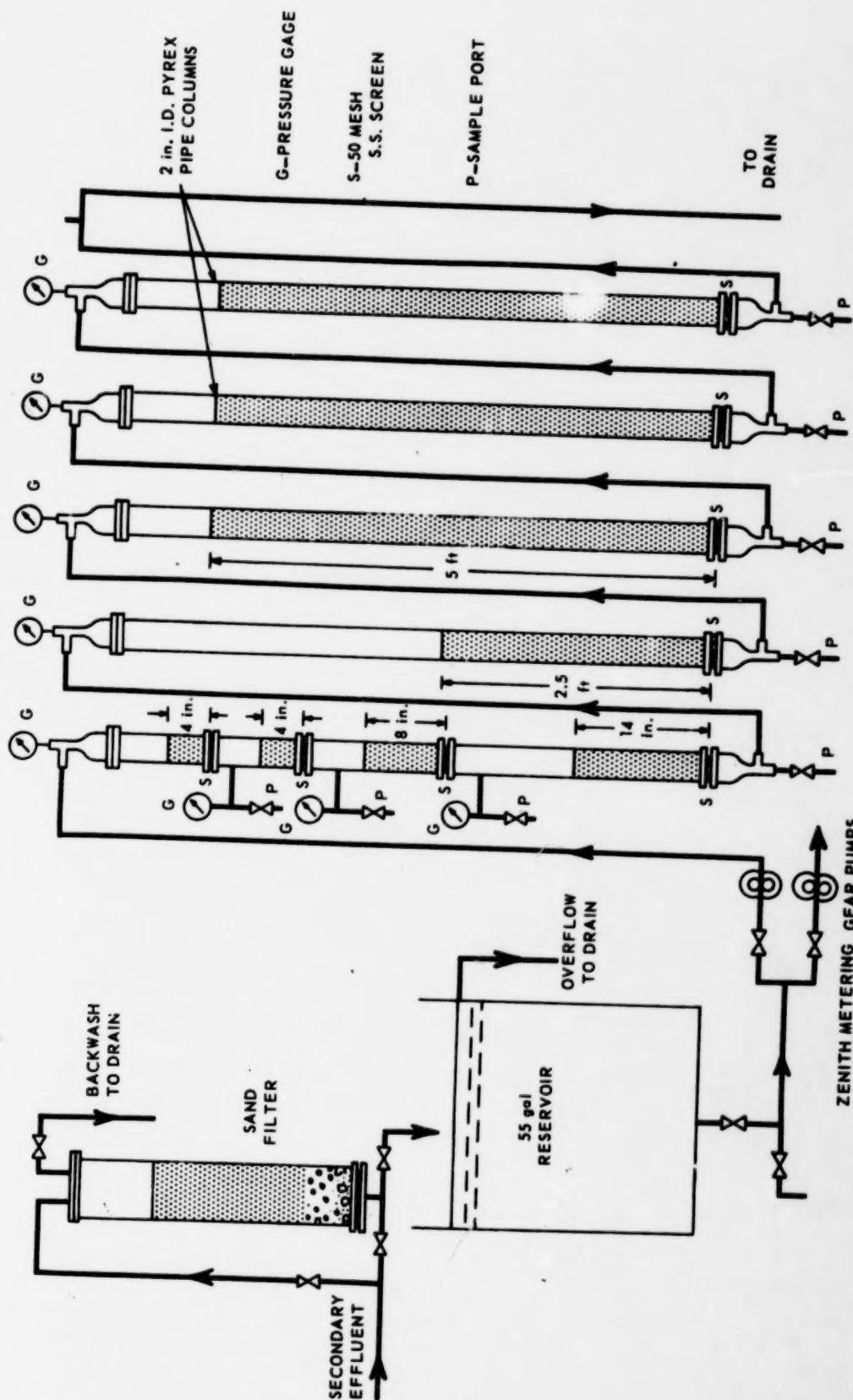


Figure 1. Apparatus for column tests on secondary effluent at 4 gpm/ft².

Samples of the influent to the column system and of the effluents from the various bed depths were collected at regular intervals and composited for ABS and COD analyses. Samples for ABS determinations over the first 4 days of operation were collected once an hour and composited over 6-hour periods. All the other samples shown were collected at 6-hour intervals and composited over 24 hours.

CARBON FILTER MONITOR TESTS

Time of contact between the water and activated carbon is an important factor in adsorption efficiency. In order to determine if the passage of some organic matter through the column was occurring because of insufficient contact time or the spent condition of the carbon, special monitoring filters were installed to check the influent and effluent of the 20-foot column system. Fresh carbon was used in the monitoring filters and the contact time employed was sufficient to make certain that virtually all matter that could be removed by adsorption on activated carbon was removed. The monitoring filters were operated for the last 4 days of the column test on secondary effluent at 4 gpm per square foot.

Apparatus

Two Pyrex glass columns, 12 in. long x 1 in. i.d.

Pittsburgh activated carbon, Type SGL, 8 x 30 mesh

Zenith metering unit fitted with two pumps

Three Soxhlet extraction assemblies (43 x 123 mm thimbles)

Small tared vials.

Procedure

Two 70-gram portions of Type SGL carbon were washed with boiling distilled water and charged to the columns. Filtered secondary effluent from the 55-gallon reservoir feeding the column system was pumped through one of the filters at a flow rate of 20 milliliters per minute. Treated effluent from the 20-foot bed was pumped upflow through the second filter at the same flow rate. After a total volume of 100 liters had passed through each filter the carbon was discharged and dried overnight in an atmosphere free of organic contaminants.

The air-dried carbon was transferred to Soxhlet extractors and extracted overnight with 300 milliliters of chloroform. The chloroform extracts were evaporated on a hot plate at low heat to a volume of approximately 5 milliliters. A sample of virgin carbon was subjected

to the same washing, drying, and extraction procedure. Each concentrated extract was transferred to a tared vial. The extraction receivers were rinsed twice and the rinses were combined with the concentrate in each case. The extracts were air evaporated to dryness and the vials weighed.

The carbon samples were removed from the thimbles, dried, and the extraction procedure was repeated with ethyl alcohol.

COLUMN TESTS ON PRIMARY EFFLUENT

The apparatus used was identical to that described previously for the column tests on secondary effluent at a flow rate of 10 gpm per square foot, except that the 4-inch i.d. sand filter was replaced with a 6-inch i.d. unit.

At the Pleasant Hills Plant primary effluent was withdrawn continuously from the mixing channel beyond the primary settling tanks by gravity flow through a rubber hose to a 55-gallon drum housed in the raw waste-water wet well. From there it was pumped through the sand filter to the 55-gallon drum, which served as the reservoir for the column assembly.

An attempt was made to operate the column system at a flow rate of 10 gpm per square foot, but operational difficulties made it impossible to maintain a constant flow rate.

Composite samples of the influent to the column system and of the effluent from each 5-foot bed section were collected twice a week at 6-hour intervals over a 24-hour period for ABS and COD analyses. Twenty-four-hour composite samples of the column influent and the effluent from the 20-foot bed were also collected twice a week for 5-day BOD determinations. The latter were collected over the same period that the plant control BOD samples were composited.

Cyclic Reactivation Tests

Sufficient type SGL carbon for a 5-foot bed (1,360 g) was charged to a 2-inch i.d. Pyrex pipe column. Filtered secondary effluent from the 55-gallon reservoir was pumped through the column at a flow rate of 10 gpm per square foot. The bed was backwashed at intervals to eliminate the accumulation of suspended solids and prevent excessive pressure drop. After approximately 6,000 gallons of secondary effluent had passed through the bed, the carbon was removed from the column and reactivated to its virgin apparent density in the laboratory rotary furnace at 1,740°F by using a 34 percent by volume steam, 66 percent by volume air atmosphere. Standard activity tests were performed on samples of the spent and reactivated material. The reactivated carbon, plus sufficient virgin material to restore the charge to its original

weight, was returned to the column and the contacting with secondary effluent until exhaustion was repeated. The spent carbon was then reactivated a second time. The exhaustion and reactivation operations were continued for 16 cycles. After the 10th and 15th exhaustion-reactivation cycles, the performance of the reactivated carbon was compared to that of virgin carbon by operating adsorption columns in parallel on secondary effluent. A bed depth of 5 feet was employed and the flow rate adjusted through each 2-inch i.d. column so that the contact time in the bed was equivalent to that achieved through a 20-foot bed depth at a flow rate of 10 gpm per square feet. The bed volume of the contactor used was 188 cubic inches and the contact time based on bed volume was 15 minutes.

Flocculation And Settling Prior To Carbon Adsorption

Alum was used as the flocculating agent in these studies. The alum treatment consisted of adding the selected amount of alum dissolved in 5 to 10 milliliters of water to 2,500 milliliters of secondary effluent, stirring well and allowing the sewage to settle for 24 hours. The settled sewage was then filtered and isotherms run.

Analytical Methods

In addition to the analytical procedures listed in the first interim report,¹ the following methods were used in the current study.

BOD - 5-day method, "Standard Methods for the Examination of Water and Waste Water," Eleventh Edition, pp. 318-323.

Residue on Evaporation - Ibid, pp. 326-327.

Nitrates, nitrites, total nitrogen, and phosphorous were determined by using procedures supplied by the Robert A. Taft Sanitary Engineering Center.

TOC - Total organic carbon determined by combustion of samples and infrared detection of CO₂ by the method of Van Hall, et al.²

RESULTS AND DISCUSSION

Isotherm Tests

Two isotherms for the adsorption of ABS by type SGL carbon from two samples of secondary effluent, collected on different days, are shown in Figure 2. The isotherms have been extrapolated to intersect a vertical line originating at the initial ABS concentration (C_0). The point of intersection $(X/M) C_0$ should represent the theoretical capacity of this carbon when it is in equilibrium with a secondary effluent of ABS concentration C_0 and a fixed COD concentration. This equilibrium should be attained in at least the upper section of a granular carbon bed through which the effluent is being percolated. Theoretical capacities of 6.0 and 8.5 grams ABS per 100 grams of carbon (Figure 2) were obtained for secondary effluents having ABS concentrations of 4.4 and 3.5 ppm and COD concentrations of 74 and 39 ppm, respectively. The reduction in ABS capacity at the larger COD concentration would be expected because of the increased competition for adsorption sites at the larger total organic content.

Isotherms for the adsorption of ABS by Types SGL and MWT carbons from the same secondary effluent (39 ppm COD and 3.5 ppm ABS) are compared in Figure 3. Type SGL, the carbon with the larger surface area, exhibited a higher $(X/M)C_0$ value (8.5 grams per 100 grams of

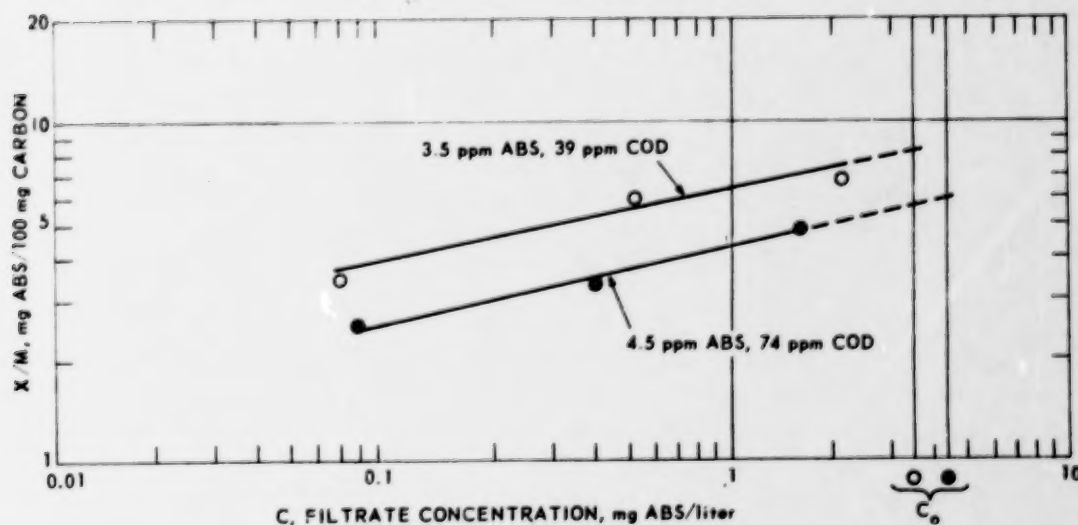


Figure 2. ABS adsorption isotherms for two different samples of secondary effluent, type SGL carbons.

carbon) than Type MWT did (6.0 grams per 100 grams of carbon). This observation is in agreement with earlier results with pure ABS solutions.

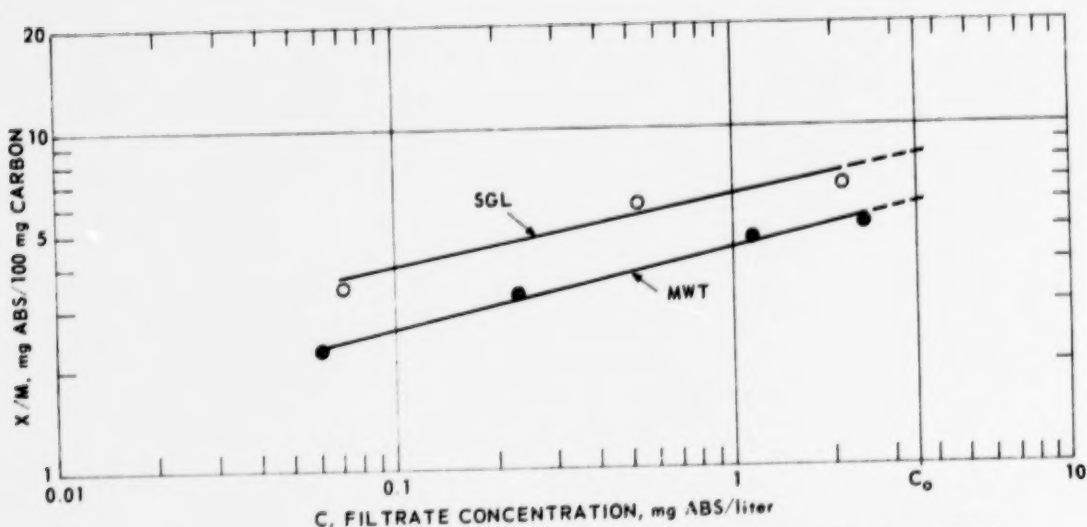


Figure 3. ABS adsorption isotherms for secondary effluent (3.5 ppm ABS, 39 ppm COD), types SGL and MWT carbons.

Typical isotherms for the adsorption of the COD constituents from secondary effluent by Types SGL and MWT carbons are plotted in Figure 4. The $(X/M)_{C_0}$ values indicate capacities of approximately 35 percent by weight for SGL and 22 percent by weight for MWT. These values are of course only rough approximations of the amount of organics adsorbed, since the COD values do not indicate the actual concentration but the weight of oxygen consumed in the standard test.

An isotherm for the adsorption of ABS from primary effluent by Type SGL carbon is shown in Figure 5. The effluent used for these tests had an ABS concentration of 5.1 ppm and a COD value of 117.8 ppm. The $(X/M)_{C_0}$ value of 4 percent by weight is markedly lower than the corresponding values for the adsorption of ABS from secondary effluent by SGL (8.5 percent by weight). This decrease in ABS capacity would, however, be expected because of the larger total organic content of the primary effluent.

The adsorption isotherm for the adsorption of COD from the same sample of primary effluent is plotted in Figure 6. It was noted above that $(X/M)_{C_0}$ values for COD must be interpreted with caution because COD values do not represent concentrations directly. The $(X/M)_{C_0}$ value of 80 percent by weight shown in Figure 6 is unrealistic and is attributed to

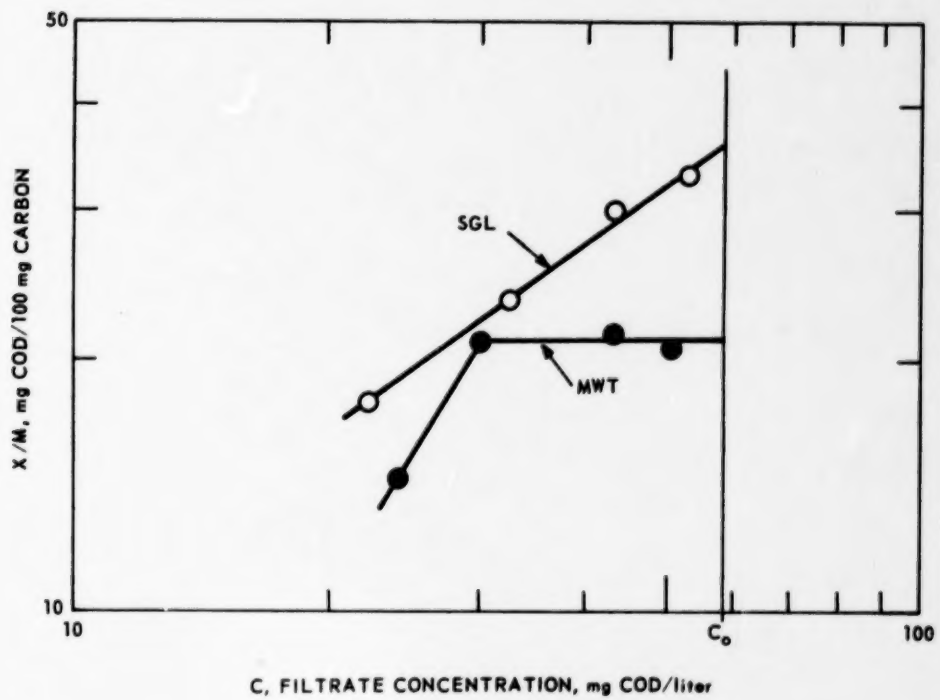


Figure 4. COD adsorption isotherms for secondary effluent (59 ppm COD, 5 ppm ABS), types SGL and MWT carbons.

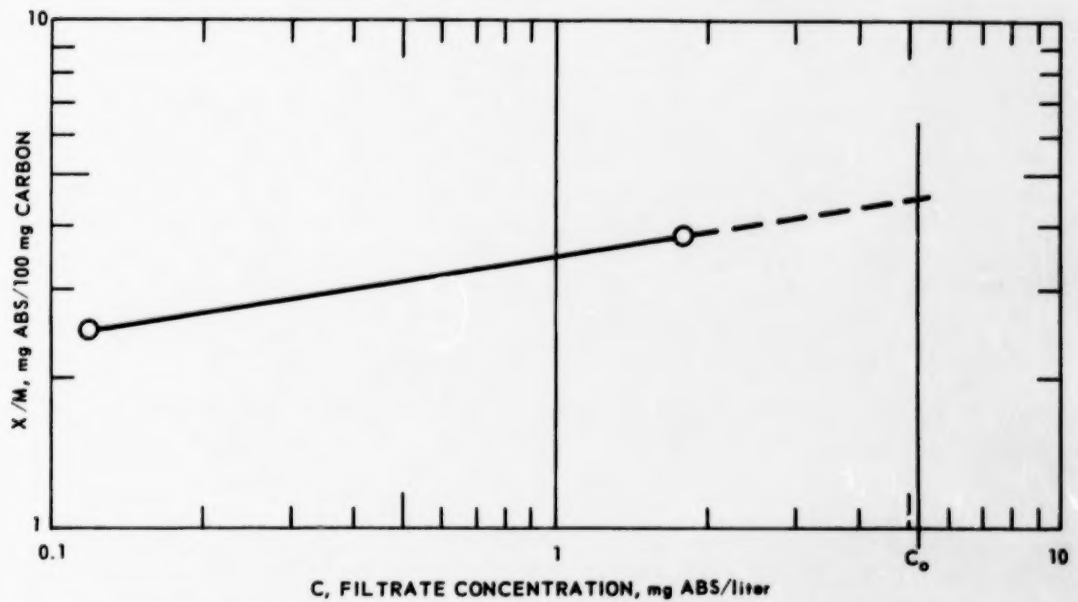


Figure 5. ABS adsorption isotherm for primary effluent (5.1 ppm ABS, 118 ppm COD), type SGL carbon.

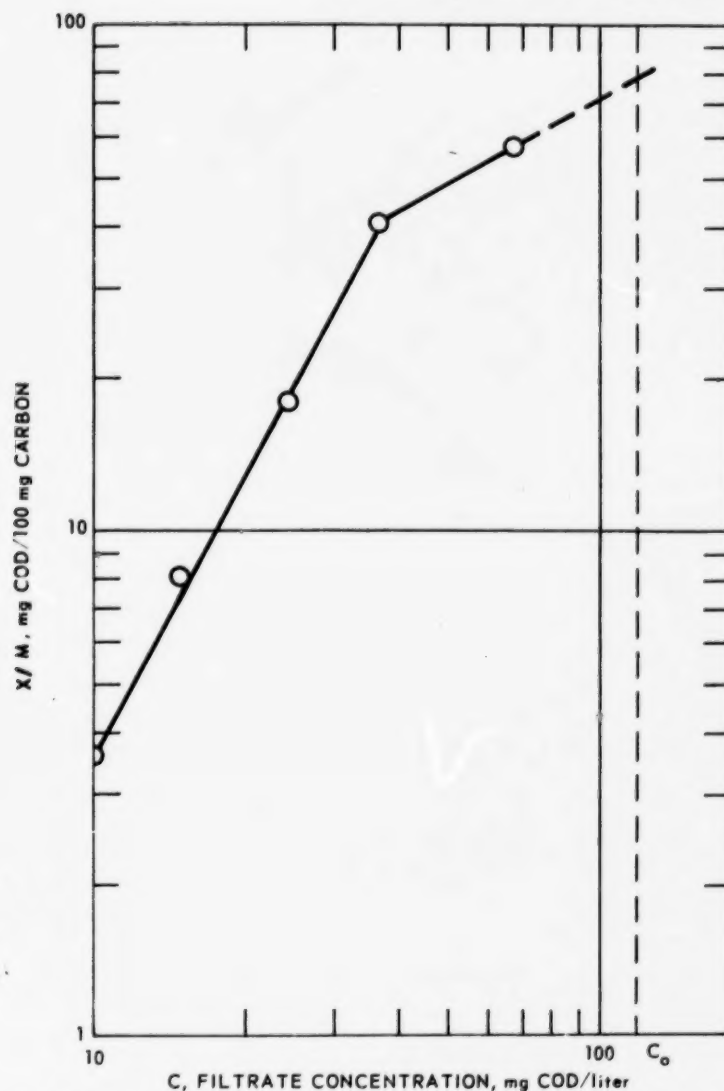


Figure 6. COD adsorption isotherm for primary effluent (118 ppm COD, 5.1 ppm ABS), type SGL carbon.

the presence of minute suspended-organic solids. It is postulated that these solids can pass through the paper used to filter the blank samples, but are mechanically trapped in the filter cake when samples containing carbon are filtered.

Column Tests

COLUMN TESTS ON SECONDARY EFFLUENT AT 4 GALLONS PER MINUTE PER SQUARE FOOT

The analytical data accumulated during the tests at 4 gpm per square foot are listed in Table 2. ABS breakthrough curves for the shallow-bed sections installed at the inlet end of the column assembly are plotted in Figure 7. The throughput volumes and the weights of ABS adsorbed at 100 percent breakthrough, calculated by graphical integration of these curves, are listed in Table 3.

Table 2. ANALYTICAL DATA, COLUMN TESTS ON SECONDARY EFFLUENT AT A FLOW RATE OF 4 GPM/FT²

Date	Throughput volume, gal	ABS concentration, ppm									COD concentration, ppm				
		Carbon bed depth, ft									Carbon bed depth, ft				
		Influent	0.33	0.67	1.25	2.5	5.0	10.0	15.0	20.0	Influent	5	10.0	15.0	20.0
7-30-62	30.5	4.1	2.2	1.2	0.2	0.0	0.1								
	61.0	4.6	3.2	2.3	0.6	0.1	0.1								
	91.5	5.3	4.3	3.3	1.6	0.3	0.1	0.1			80	49	34	31	29
7-31-62	122.0	5.0	4.3	3.5	2.0	0.5	0.1								
	153	5.2	3.5	3.5	2.2	0.6	0.1								
	183	5.4	5.0	4.0	2.7	0.9	0.1								
	213.5	5.3	4.4	4.1	2.5	0.9	0.1	0.1			123	97	57	35	31
8-1-62	244	4.8	4.3	3.8	2.6	1.0	0.2								
	274.5	4.8	4.1	4.0	2.9	1.2	0.1								
	305	4.9	4.6	3.7	3.1	1.3	0.1								
	335.5	4.7	4.3	3.7	3.1	1.4	0.2	0.1			65	54	50	30	26
8-2-62	366	4.1	3.9	3.2	2.9	1.3	0.2								
	396.5	4.0	4.0	3.5	2.8	1.1	0.1								
	457.5	4.0	3.7	3.4	2.8	1.3	0.3	0.1			71	55	23	18	15
8-3 to 8-4	580	4.0	3.6	3.4	2.8	1.5	0.3	0.1							
8-4 to 8-5	701	3.5	3.5	3.2	2.8	1.6	0.4	0.0							
8-5 to 8-6	824	3.4	3.4	3.1	2.6	1.7	0.3	0.1			59	57	29	29	28
8-7 to 8-8	1,068	3.4		3.0	2.4	1.4	0.3	0.0			60				
8-8 to 8-9	1,190	4.2		3.6	2.9	1.9	0.5	0.1			82	56	46	46	23
8-9 to 8-10	1,312	3.2		3.2	2.6	1.9	0.6	0.1			66	28	21	19	17
8-10 to 8-11	1,433	2.9													
8-11 to 8-12	1,555	3.0													
8-12 to 8-13	1,678	2.4		2.3	1.8	1.4	0.5	0.03							
8-13 to 8-14	1,800	3.1		2.8	2.4	1.8	0.8	0.04			56	23	22	21	13
8-14 to 8-15	1,922	3.1		3.1	2.8	1.9	1.1	0.06			41	23	14	12	7
8-15 to 8-16	2,044	3.1		2.6	2.6	2.1	1.1	0.08			65	37	32	33	26
8-16 to 8-17	2,167	2.6		2.3	2.1	1.9	1.6	0.04			58	27	15	14	12
8-19 to 8-20	2,540	2.8		2.4	2.1	1.7	0.8	0.1			64	44	31	26	25
8-20 to 8-21	2,650										61	32	21	20	18
8-21 to 8-22	2,780	5.0			4.3	3.5	1.7	0.1							
8-23 to 8-24	3,020	4.1			4.0	3.3	2.1	0.1			75	30	31	30	18
8-26 to 8-27	3,380	3.6			2.9	2.6	1.4	0.1	0.0		54	-	25	16	17
8-27 to 8-28	3,510										46	29	19	21	12
8-28 to 8-29	3,620	5.1			4.8	4.1	2.5	0.3							
8-30 to 8-31	3,871	4.4			4.4	3.3	2.0	0.2			51	32	20	11	10
9-2 to 9-3	4,240	2.2				1.7	1.1	0.1			26	14	9	8	10
9-5 to 9-6	4,610	2.0				1.6	1.1	0.2			37	40	16	12	9
9-9 to 9-10	5,100	3.4				2.7	1.7	0.3	0.1		47	38	23	13	16
9-12 to 9-13	5,460	3.5				3.0	2.4	0.8	0.1		44	35	23	15	15
9-16 to 9-17	5,950	3.9				2.9	2.0	0.3	0.05		50	34	25	18	17
9-19 to 9-20	6,320	4.0				4.0	2.9	1.1	0.2		44	33	22	14	10
9-23 to 9-24	6,800	4.1				3.8	3.3	1.2	0.2		70	63	43	32	26
9-30 to 10-1	7,650	2.2				2.0	1.5	0.8	0.1		39	33	29	18	11
10-3 to 10-4	8,010	3.2				2.7	2.4	1.3	0.3		45	36	28	18	12
10-7 to 10-8	8,510	3.4				3.3	2.7	1.1	0.4						
10-10 to 10-11	8,860	3.7				3.2	1.9	1.6	0.4		53	40	26	19	20
10-17 to 10-18	9,720	4.6				4.0	3.0	1.6	0.3		77	59	49	35	32
10-24 to 10-25 ^a and															
10-28 to 10-29	11,100	4.4				3.9	3.4	2.2	0.8		68	60	29	17	12
11-7 to 11-8	12,300	5.0				4.8	4.0	2.5	0.6	0.15	111	75	40	26	21
11-11 to 11-12 ^a and															
11-14 to 11-15	13,150	3.6				3.4	2.9	1.9	0.6	0.17	103	52	43	31	25
11-18 to 11-19 ^a and															
11-21 to 11-22	14,040	3.7				3.1	3.0	2.2	0.7	0.16	96	44	38	28	21
11-25 to 11-26 ^a and															
11-28 to 11-29	14,900	3.9				3.5	3.1	1.7	0.7	0.16	68	52	44	23	21
12-1-62	15,100	(No analysis)													

^a For the ABS determination, equal volumes of both composites were used. The COD concentration was determined only on the second composite of each set.

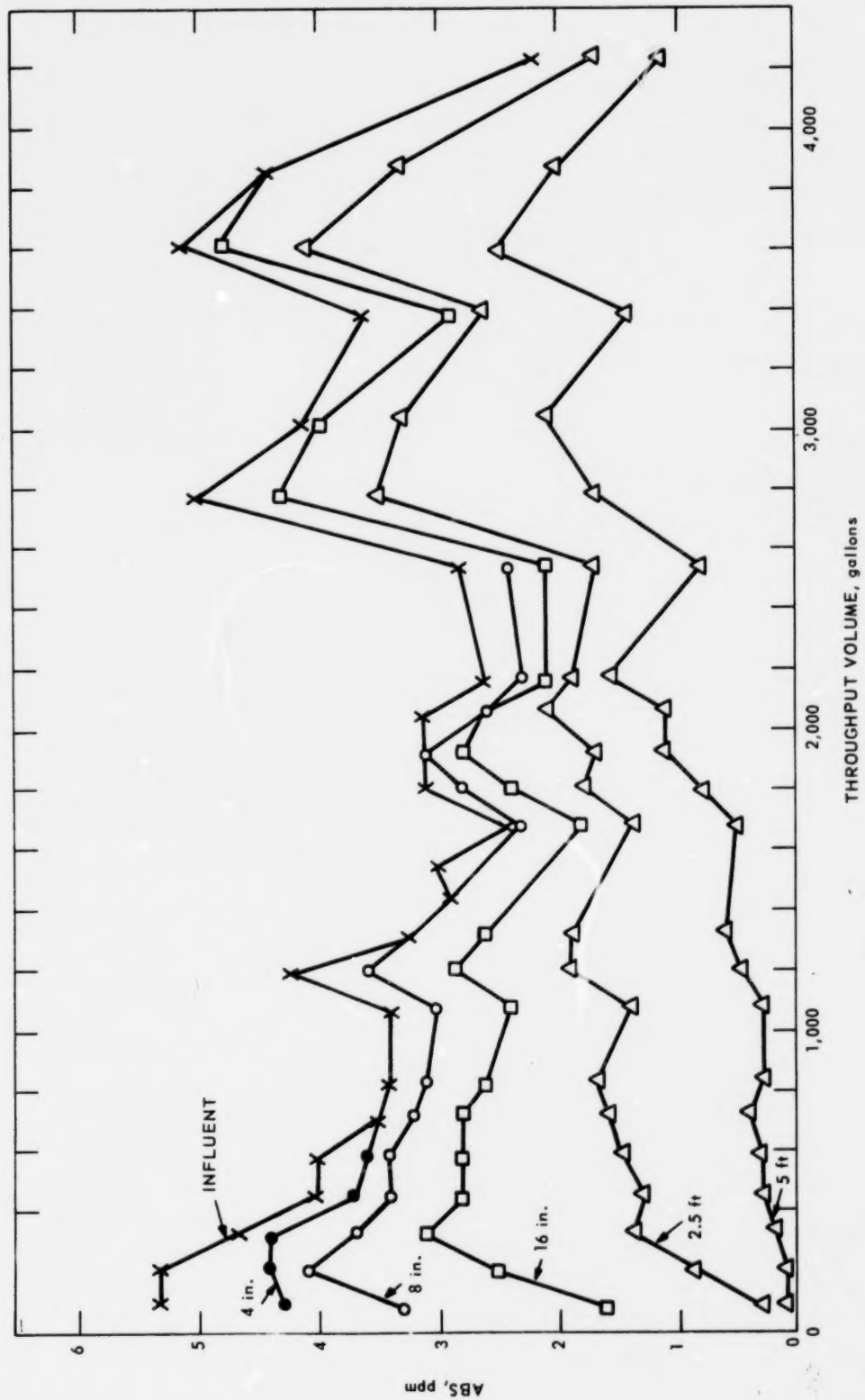


Figure 7. ABS breakthrough curves for shallow bed depths, secondary effluent at 4 gpm/ft².

Table 3. THROUGHPUT VOLUMES AND TOTAL ABS ADSORBED FOR THE TREATMENT OF SECONDARY EFFLUENT IN SHALLOW BEDS AT 4 GPM/FT²

Bed depth, ft	Throughput ^a volume, gal	Total ABS adsorbed, g/100 g C
0.33	825	1.65
0.67	2,540	2.6
1.33	3,870	3.3
2.5	>15,000	6.5

^a To 100% breakthrough.

The observation that the weight of ABS adsorbed on the carbon (Table 3) increases with bed depth is attributed to the preferential adsorption of more strongly adsorbed COD constituents in the upper sections of the bed. It is at first glance surprising that the first 2.5 feet of bed adsorbed a total of 6.5 grams of ABS per 100 grams of carbon whereas the first 1.3 feet adsorbed only 3.3 grams per 100 grams. These figures suggest that the second 1.2-foot section adsorbed approximately 10 percent by weight to give an overall figure of 6.5 percent by weight for the first 2.5-foot section. From the isotherm data one would expect a maximum capacity of approximately 6 percent by weight. If, however, strongly adsorbed organics other than ABS are removed in the first 1.3-foot section, the second 1.2-foot section would be subjected to an influent of reduced COD content during the first part of the test and consequently could have a larger capacity than a predicted value. The fact that the capacity of the carbon for ABS increases with diminishing COD content is apparent from the isotherms (Figure 2).

ABS breakthrough curves for the 10-, 15-, and 20-foot bed depths and COD curves for the 10- and 15-foot depths are plotted in Figure 8. The COD curve at the 20-foot depth has been omitted since the last 5-foot section reduced the COD content from an average value of 22 ppm to an average of only 18.5 ppm during the test period. It is immediately apparent from these data that the residual COD, which averages 16 ppm from a 20-foot bed at 10 gpm per square foot, and 18.5 ppm in the current tests at 4 gpm per square foot from the same bed depth, was not decreased by more than a twofold increase in contact time.

This residual could not be reduced by filtering the column effluent through a 10- or a 5-micron millipore filter, which indicates that it is not due to suspended solids. The possibility that it may be due to

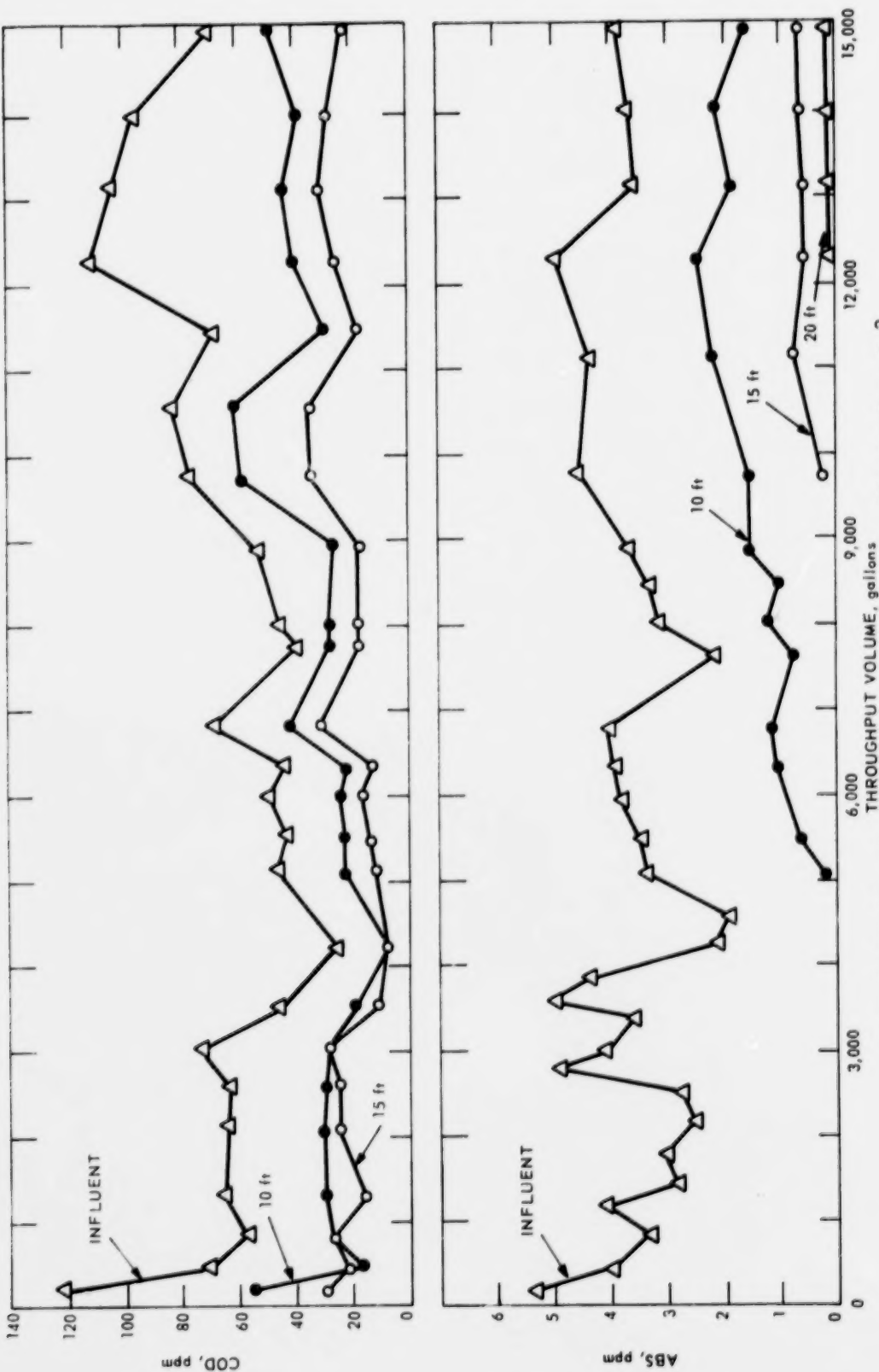


Figure 8. Breakthrough curves, column tests on secondary effluent at 4 gpm/ft².

colloidal material or difficultly adsorbable, soluble organic matter has not been precluded. The results of two COD isotherm tests on the effluent from the 20-foot bed are listed in Table 4. They indicate that the COD residual can be reduced to negligible concentrations by pulverized carbon treatment. Prohibitively large carbon dosages are, however, required.

Table 4. COD ISOTHERM TESTS ON EFFLUENT FROM 20-FT BED WITH TYPE SGL CARBON

Carbon dosage, mg/liter	Residual COD concentration, ppm	
	Test 1	Test 2
0	29	17.6
400	11	6.2
1,200	5.8	2.2
5,000	3.2	2.2

During the tests at 4 gpm per square foot, a total of approximately 15,000 gallons of secondary effluent was passed through the column assembly over a 4-month period. At the termination of the test the effluent from the 20-foot bed had an ABS content of 0.2 ppm and was colorless, nonfoaming, and odorless.

The data on column performance calculated from the ABS breakthrough curves in Figure 8 are summarized in Table 5. The single-column dosages were calculated from the throughput volumes to a 0.5-ppm ABS breakpoint from each bed depth and the total weight of carbon in that bed. Countercurrent dosage at the 15-foot bed depth was calculated from the throughput volume and the weight of carbon in a single 5-foot bed on the assumption that the first 5 feet of bed would be removed for reactivation and replaced with fresh carbon at the outlet end when the breakpoint was reached. Accurate dosage figures for a 20-foot column are not available since the test was not continued to a 0.5-ppm ABS breakpoint from the fourth 5-foot section. From the throughput volume treated in the 20-foot bed, it is, however, obvious that the countercurrent dosage computed in like manner would have been less than 0.2 pound per 1,000 gallons for the first cycle.

The countercurrent dosage in cyclic operation will increase after the first cycle until steady state conditions have been established, for two reasons. First, in the second and subsequent cycles the throughput volume will decrease since the carbon remaining in the column will be partially spent. Second, the activity of the reactivated carbon would be expected to decrease to some extent from its virgin level. To operate the 20-foot bed at the 4 gpm per square foot flow rate for more than one cycle would have required a prohibitively long time. Consequently, an accurate prediction of the ultimate countercurrent dosage cannot be made from the existing data. It can, however, be estimated that it would be be-

Table 5. SUMMARY OF DATA, COLUMN TESTS ON SECONDARY EFFLUENT AT 4 GPM/FT²

Depth, ft	Contact time ^a based on bed volume, min.	Throughput ^b volume, gal	Average COD, ppm ^b		Average ABS, ppm		Carbon Dosage, lb/1,000 gal	
			Influent	Effluent	Influent	Effluent	Single column	Counter-current ^c
5	9.4	1,190	78.3	25	4.2	<0.5	2.52	-
10	18.7	5,460	61	18	3.5	<0.5	1.10	-
15	28.1	11,000	60	18.5	3.6	<0.5	0.82	0.26
20	37.4	>15,000	72	18.5	3.8	<0.5	<0.80	<0.2

^a Contact time based on bed volume, min. = Length of column, ft $\div \frac{\text{gpm/ft}^2}{7.5}$

^b To 0.5 ppm breakpoint.

^c Five-ft columns in series, first column reactivated after breakthrough from last.

tween the countercurrent dosage obtained for the first cycle and the dosage in single-column operation. For a 15- to 20-foot column, it would be between 0.2 and 0.8 pound per 1,000 gallons. A figure of 0.75 pound per 1,000 gallons is considered conservative. The effect of the displacement phenomenon for ABS and its relationship to dosage will require study before firm dosage estimates can be made.

A direct comparison of the data at 4 gpm per square foot with the earlier data at 10 gpm per square foot is difficult because of the natural fluctuations in the ABS and COD contents of the secondary effluent. In an attempt to compare the results from the two tests, the following procedure was used. For the first cycle at 10 gpm per square foot and the 4 gpm per square foot tests (Table 2) the ABS concentrations in the column effluents were converted to fractional values (C/C_0) by dividing each effluent concentration by the corresponding influent concentration. Plots were made of C/C_0 at 10 gpm per square foot against the total weight of ABS in the influent for 5-, 10-, 15-, and 20-foot bed depths. The data for the 4 gpm per square foot flow rate were plotted for each bed depth investigated and interpolations were made to estimate breakthrough curves for 2-, 4-, 6-, and 8-foot bed depths in order to make comparisons at residence factors approximately equal to those for 5-, 10-, 15-, and 20-foot beds at 10 gpm per square foot. The C/C_0 values from the four estimated breakthrough curves at 4 gpm per square foot were plotted against ABS throughput on a weight basis on the same graph as the 10 gpm per square foot data. The resulting plots are shown in Figure 9.

Note in this comparison of the data that there were appreciable differences in the ABS concentrations of the influents between the two

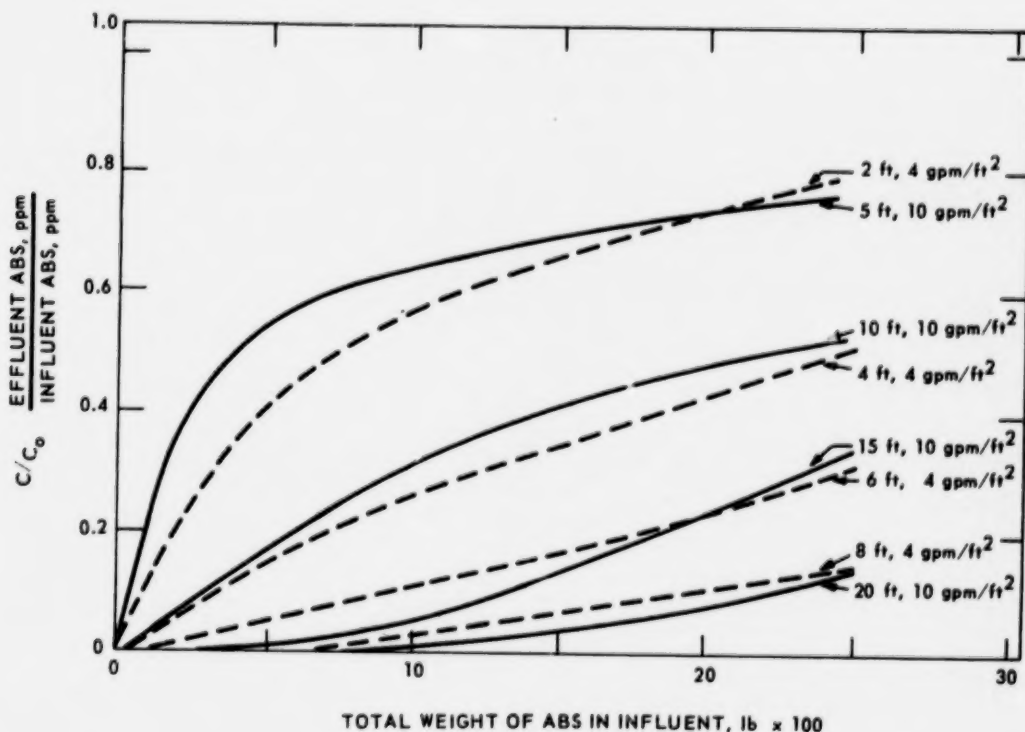


Figure 9. Comparison of ABS breakthrough curves at 10 gpm/ft² with calculated curves for the same residence factors at 4 gpm/ft².

runs. The influents averaged 70 ppm COD and 5.5 ppm ABS for the 10 gpm per square foot tests and 72 ppm COD and 3.8 ppm ABS for the 4 gpm per square foot tests. Nevertheless, the curves for corresponding residence times in Figure 9 coincide well. The fact that the results from the two tests can be correlated in this manner indicates that, for secondary effluents of these approximate compositions, the dosages obtained here can be obtained over a considerable range of flow rates provided that the bed is of sufficient depth to give the required contact time.

Table 6 summarizes the results of miscellaneous analytical determinations performed during the test period. The data indicate that the total nitrogen, nitrate, nitrite, phosphorus, and chloride content of the secondary effluent, as well as the residue on evaporation are not appreciably affected by granular carbon treatment.

The increases in pressure exhibited by various sections of the bed are plotted as a function of time for the first 39 days of operation in Figure 10. The distribution of pressure drop across the 20-foot bed after 39 days is given in Table 7. It is noteworthy that 96 percent of the total pressure drop occurred over the first 2.5-foot section. At the end of this period the carbon was removed from the initial bed sections, washed thoroughly, and recharged to the same section. A considerable quantity of slimy, grayish, solid material was washed from the carbon. No convenient test was available to determine whether this accumulation

Table 6. MISCELLANEOUS ANALYTICAL RESULTS ON SECONDARY EFFLUENT BEFORE AND AFTER COLUMN TREATMENT AT 4 GPM/FT²

Days of operation	Bed depth, ft	Total N, ppm	NO ₃ ⁻ , ppm	NO ₂ ⁻ , ppm	P, ppm	Cl ⁻ , ppm	Residue on evaporation, ppm
56	Influent	23.2	81.0	1.65	44.6	69.6	-
	2.5	-	79.2	0.76	39.0	-	-
	5.0	27.6	77.9	1.31	39.0	68.5	-
	10.0	24.7	74.1	0.31	42.4	70.7	-
	15.0	-	73.8	0.33	41.2	71.1	-
	20.0	24.7	73.6	0.93	41.2	70.9	-
63	Influent	7.3	111.7	0.53	26.6	59.3	835
	2.5	-	100.2	0.38	27.1	-	824
	5.0	8.9	101.2	0.28	26.6	59.3	816
	10.0	9.1	107.1	0.43	26.6	61.1	823
	15.0	-	102.0	0.22	26.6	10.0	812
	20.0	8.7	109.1	0.31	26.6	62.1	817

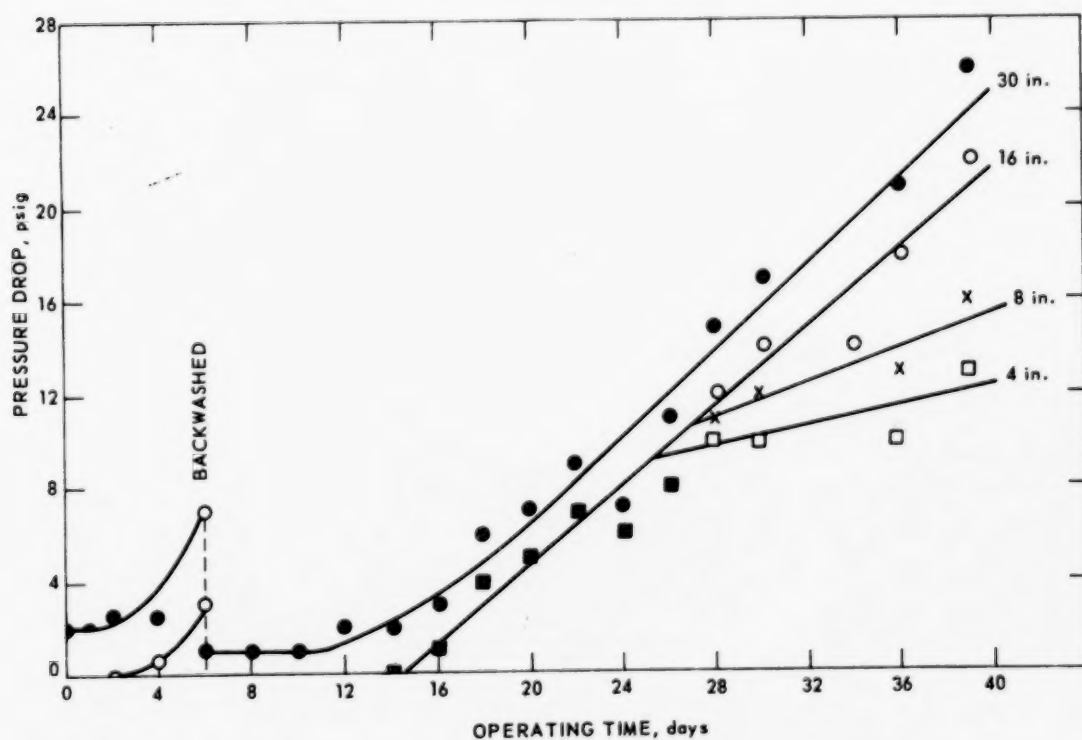


Figure 10. Pressure drop across various bed depths at 4 gpm/ft².

Table 7. PRESSURE DROP BUILDUP AT VARIOUS BED DEPTHS
AFTER 39 DAYS OF COLUMN TREATMENT OF SECONDARY
EFFLUENT AT A FLOW RATE OF 4 GPM/FT²

Bed depth from influent end, ft	Pressure, psi	% of total pressure
0.33	11	40.7
0.67	15	55.5
1.33	22	81.5
2.5	26	96.4
20.0	27	100.0

resulted from suspended solids not removed from the sand filter or from bacterial slimes. It seems unlikely, however, that the latter would be confined to the first 2.5-foot section, and an accumulation of suspended solids seems to be a more plausible explanation.

CARBON FILTER MONITOR TESTS

The results of the chloroform and ethyl alcohol extractions of the two monitor beds through which equal volumes of secondary effluent and the effluent from the 20-foot carbon bed were passed are listed in Table 8.

Table 8. CHLOROFORM AND ETHYL ALCOHOL
EXTRACTABLES, CARBON FILTER
MONITOR TESTS

	Chloroform ^a extractables, mg/l	Ethyl alcohol ^a extractables, mg/l	Total, mg/l
Carbon treated with secondary waste water	2.82	5.13	7.95
Carbon treated with the effluent from the 20-ft carbon bed	0.61	2.8	3.41

^a After correction for the weight of chloroform and ethyl alcohol extractables present in virgin carbon.

Experience at the Robert A. Taft Sanitary Engineering Center has indicated that the contact time and carbon dosage employed with the monitoring filter is such that virtually all material that is adsorbable on activated carbon and removable by the extraction technique will be measured. On this basis it can be stated that the 20-foot column reduced the content of chloroform extractables 78 percent and the content of alcohol extractables 45 percent.

COLUMN TESTS ON PRIMARY EFFLUENT

The analytical data accumulated during the column test on primary effluent are listed in Table 9. In spite of the fact that a larger sand filter was installed for this test, it removed only a part of the suspended solids in the primary effluent. As a result the solids entered the carbon column system, and this caused rapid increases in pressure drop and widely varying flow rates.

During the 26-day period in which the test was conducted, the ABS in the column influent, averaging 5.6 ppm, was for all practical purposes completely removed in the 20-foot column. Five-day BOD tests showed that the BOD was reduced from an average of 154 in the column influent to an average of 67 ppm in the effluent. During the test period, the BOD values of the plant primary effluent were reduced from an average of 126 ppm to an average of 18 ppm by the activated-sludge secondary treatment. For the first 15 days of operation, COD values averaged 249 ppm in the column influent and 92 ppm in the effluent from the 20-foot bed. For the remainder of the test period, the samples were filtered through a 10-micron filter prior to the COD determinations. This expedient reduced the influent COD to an average of 92 ppm and the effluent to 47 ppm, indicating that a considerable fraction of the COD was due to suspended matter that was only partially retained in the carbon column.

It was obvious that the suspended matter in the primary effluent was different from that in the secondary effluent. The solids in the latter could be retained in the first 2.5-foot bed section, whereas the solids in the primary effluent could not be retained in the 20-foot bed. This consideration coupled with the unsatisfactory COD and BOD reductions effected in these tests led to the conclusion that further work on the treatment of primary effluent by granular carbon columns was not justified.

Table 9. ANALYTICAL DATA, COLUMN TESTS ON
PRIMARY EFFLUENT

Days of operation	ABS, ppm					COD, ppm				
	Influent	Bed depth, ft				Influent	Bed depth, ft			
		5	10	15	20		5	10	15	20
1	5.9	1.0	0.7	0.2	0.2	151	121	82	62	55
4	6.8	2.3	0.2	0.1	0.1	257	181	81	57	52
8	6.1	4.3	1.5	0.4	0.4	281	444	240	120	154
12	5.2	3.6	0.4	0.2	0.2	980 ^a	1,770	203	106	94
15	6.9	4.6	0.9	0.3	0.2	306	403	120	68	103
							55 ^b			39 ^b
22	5.1	5.1	1.7	0.2	0.1	183				86
						86 ^b	64 ^b	56 ^b	59 ^b	70 ^b
26	3.2	1.1	0.2	0.1	0.05	98 ^b	45 ^b	35 ^b	34 ^b	32 ^b
Average	5.6					236				91
						92 ^b				47 ^b

Days of operation	BOD, ppm				
	Plant data			Column data	
	Raw sewage	Primary effluent	Secondary effluent	Primary effluent after sand filter	Primary effluent after 20-ft column treatment
2	161	85	6	135	39
6	223	140	6	153	71
9	194	162	18	207	79
13	253	165	10	242	112
16	-	-	-	197	67
20	216	129	38	107	51
23	101	77	30	37	49
Average	191	126	18	154	67

^a Not included in average.^b Filtered through No. 3 Whatman paper and a 10- μ millipore filter.

Cyclic Reactivation Tests

The properties of the spent and subsequently reactivated carbon from the cyclic reactivation tests on secondary effluent for 16 complete cycles are listed in Table 10. The properties of the virgin carbon are included. Based on apparent density differences, the average weight of contaminants adsorbed per cycle was 9.3 percent. This value could be low since the spent carbon was dried at 240°F prior to the apparent density determination, and volatile adsorbates could have been lost in this step.

Standard activity tests indicated that the molasses number could easily be maintained at essentially virgin level and that the iodine number decreased from its virgin value of 942 to about 750 during the 16 cycles. It is believed that a decrease in iodine number of this magnitude would not seriously impair the adsorptive properties of the carbon. The total ash increased from 5.36 to 13.2 percent by weight and the acid soluble ash increased from 0.94 to over 9 percent. These figures indicate that the ash accumulated during the treatment of secondary effluent is predominantly acid soluble. The amount of virgin carbon added after each reactivation to compensate for cyclic losses (samples not included) averaged 4.6 percent by weight.

The results of the comparison of virgin and regenerated carbon after 10 of the exhaustion-regeneration cycles are shown in Figure 11. Twenty-four-hour composite samples taken at 4-hour intervals were collected twice a week for analysis. The ABS breakpoint of 0.5 ppm was reached when 1,360 gallons of secondary effluent was passed through the virgin carbon bed and 1,100 gallons of secondary waste-water passed through the reused carbon bed. Better performance with the virgin carbon is indicated although the reactivated carbon possesses a sizeable capacity for ABS removal. A greater capacity for COD removal also is exhibited by the virgin carbon bed. After passage of 1,900 gallons of secondary waste-water effluent with an average COD concentration of 58 ppm, the effluent from the virgin bed averaged 22 ppm COD whereas the effluent from the 10 exhaustion-regeneration cycles averaged 28 ppm. In a comparison of results for the last 300 gallons filtered, the COD of the effluent from the virgin bed was 55 percent of the influent COD, whereas that from the reactivated carbon was 85 percent.

The results with virgin and regenerated carbon after 15 exhaustion-regeneration cycles are compared in Figure 12. Twenty-four-hour composite samples for these analyses were collected at 15-minute intervals by means of a solenoid-operated automatic sampler. In addition to providing ABS and COD data, the samples were analyzed for organic carbon by a new technique;² the results are presented in Figure 13. Figure 12 shows the ABS breakthrough of 0.5 ppm was

Table 10. PROPERTIES OF SPENT AND 10TH CYCLE REACTIVATED CARBON USED FOR CYCLIC REACTIVATION TESTS ON SECONDARY EFFLUENT

Cycles	Apparent density, g/cc		Pickup, % ^b	Iodine No.		Molasses No.		Total ash, % - Wt		Acid soluble ash, % - Wt		Reactiva- tion ^c losses, %
	Spent	React.		Spent	React.	Spent	React.	Spent	React.	Spent	React.	
0 ^a	0.485		-	942		195		5.36		0.937		-
1	0.541	0.488	11.6	759	1032	201	218	5.96	6.33	1.51	1.78	0.90
2	0.530	0.478	8.6	800	1004	198	224	6.72	7.26	2.48	2.74	5.5
3	0.532	0.479	11.3	727	934	192	217	7.25	7.80	2.9	3.08	3.7
4	0.524	0.485	9.5	688	905	174	200	7.97	8.28	3.35	3.50	3.2
5	0.531	0.480	9.5	699	857	186	214	7.51	8.55	3.26	4.03	7.1
6	0.525	0.480	9.4	647	824	165	203	8.85	9.15	4.25	4.39	6.0
7	0.528	0.482	10.0	656	856	183	195	8.85	9.30	4.53	4.72	4.3
8	0.521	0.483	8.3	621	836	176	203	9.27	9.97	4.85	6.23	6.0
9	0.520	0.482	7.7	608	782	177	198	9.51	10.72	6.04	7.42	7.4
10	0.527	0.483	9.5	603	822	192	213	9.62	10.82	6.40	7.62	4.0
11	0.529	0.490	9.5									4.1
12	0.521	0.478	6.4									3.7
13	0.521	0.482	9.0	551	716	195	210					3.9
14	0.529	0.475	9.8									4.4
15	0.530	0.475	11.6	581	755	208	232	11.55	12.9	7.94	9.62	5.3
16	0.510	0.470	7.4	603	782	213	249	11.47	13.2	7.83	9.32	4.7
			Avg.									4.64
			9.3									

^a Virgin Carbon.^b Based on Apparent Density Difference.^c Losses include those of handling and carbon burnoff.

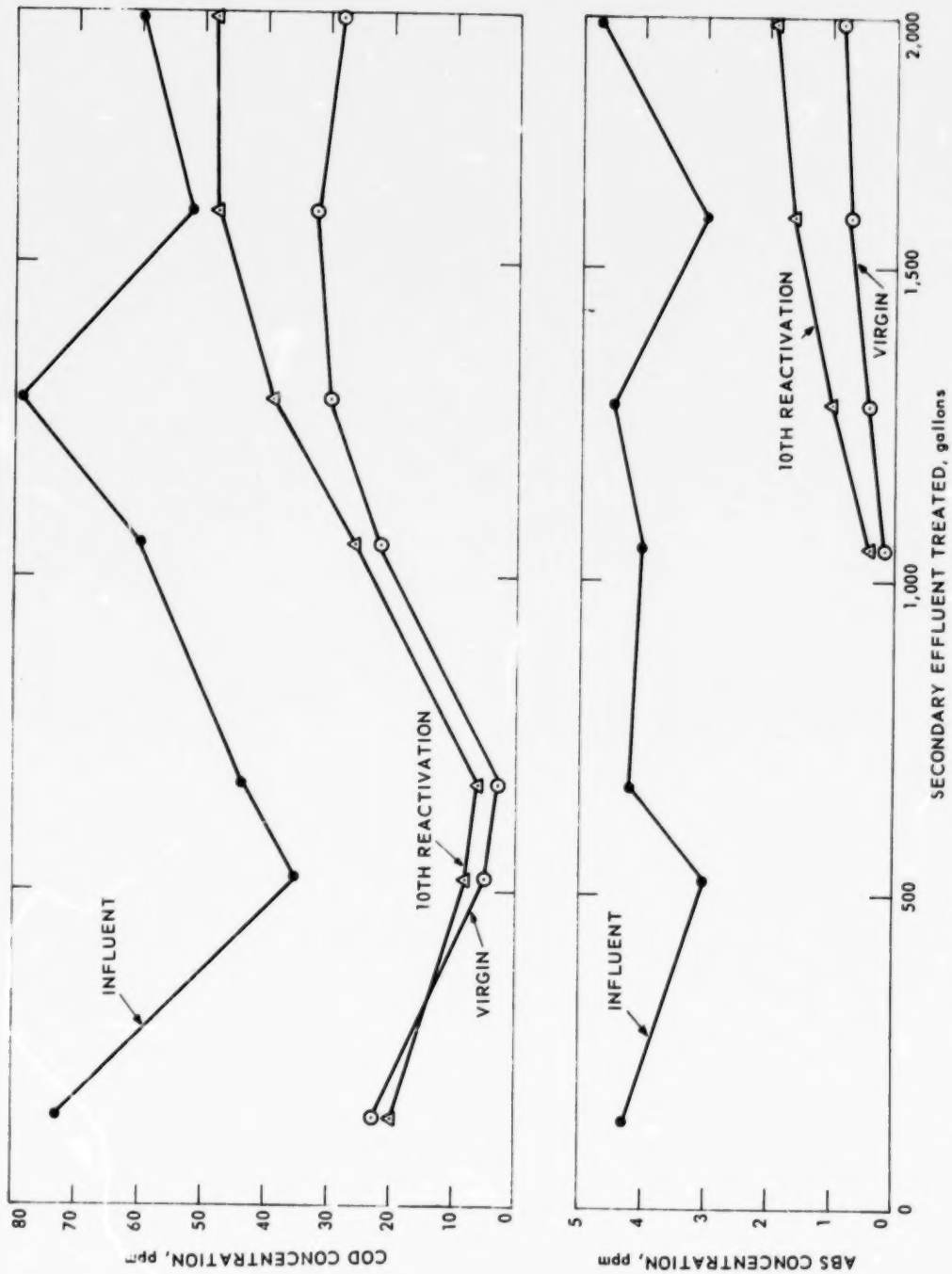


Figure 11. COD and ABS removal performance of virgin and 10-cycle reactivated carbon.

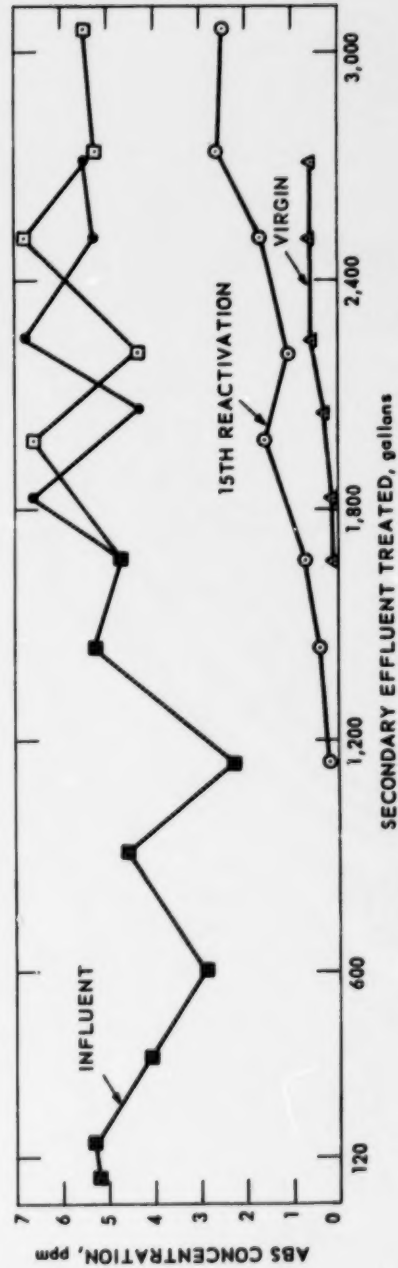
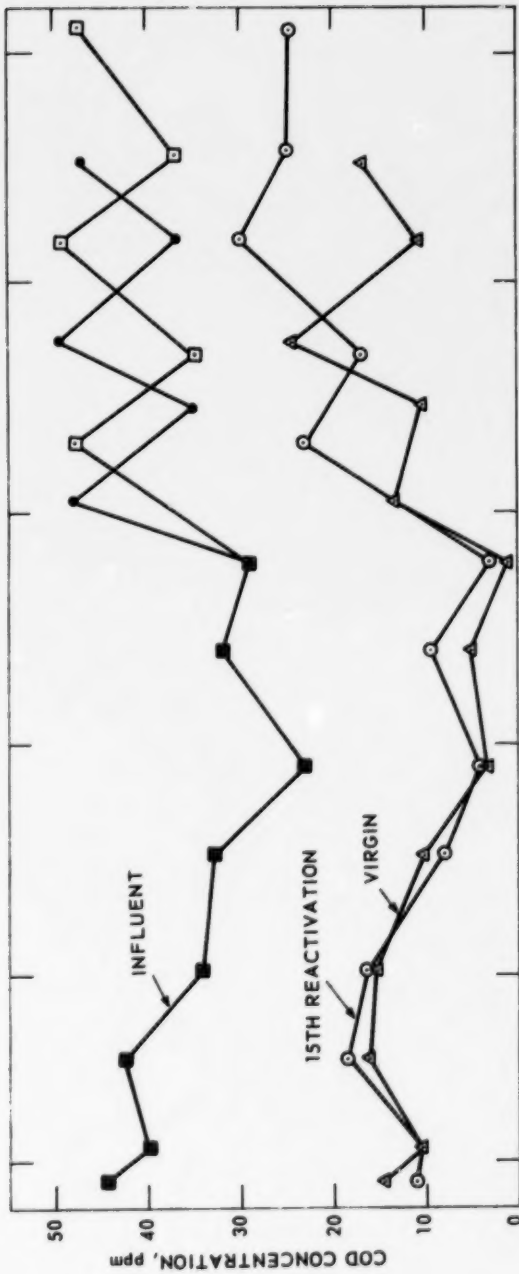


Figure 12. ABS and COD removal performance of virgin SGL carbon and 15-cycle reactivated carbon.

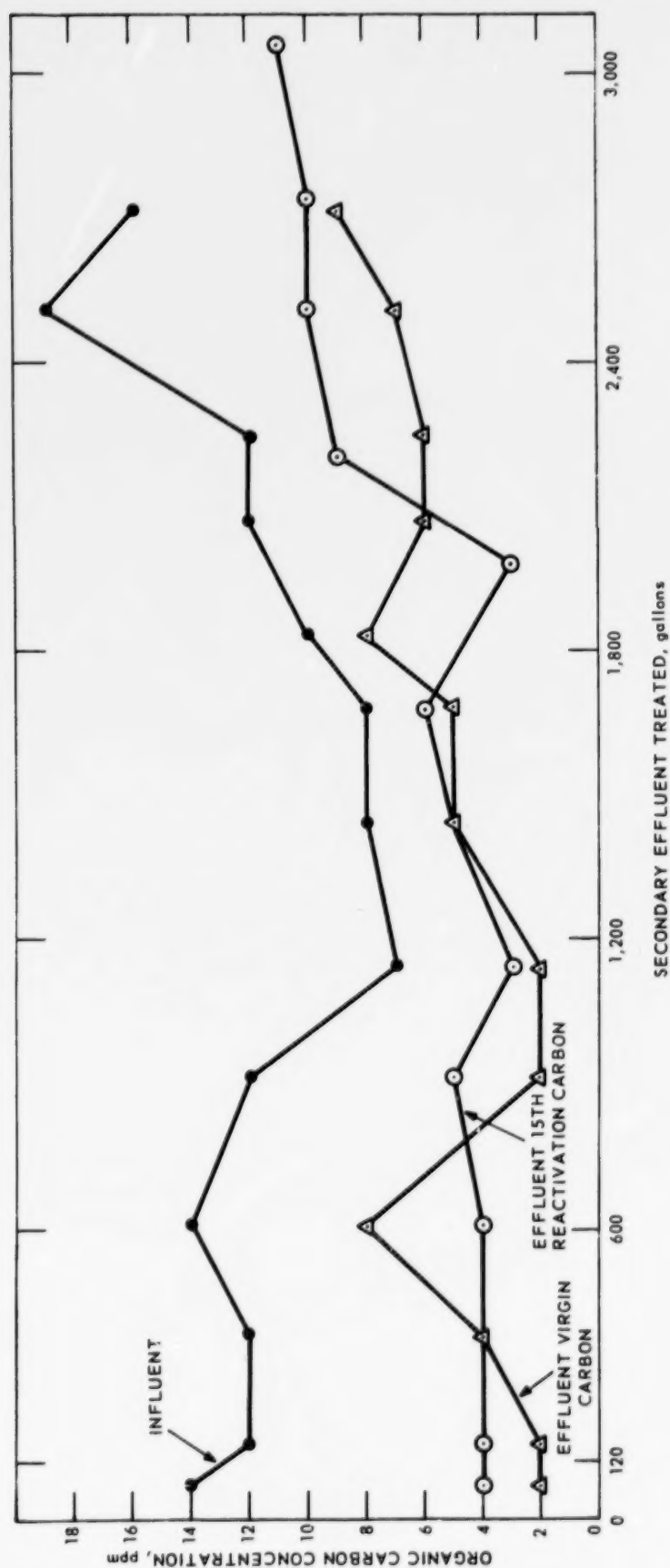


Figure 13. Organic carbon removal performance of virgin SGL carbon and 15-cycle reactivated carbon.

reached when 1,980 gallons of secondary effluent was passed through the virgin carbon bed and 1,200 gallons was passed through the reused carbon bed. A greater capacity for COD removal also is exhibited by the virgin carbon, but the results are not easy to quantitate. The results of the organic carbon measurement (Figure 13) are interesting in that they indicate both carbons are capable of producing an effluent with 4 milligrams per liter or less organic carbon on this type of feed. A period of relatively high concentrations of TOC in the effluent from the virgin bed is an artifact of the data that is difficult to explain. The two columns did not appear to differ significantly in the volume of water processed before adsorption efficiency, as measured by organic carbon analysis, decreased.

The standard procedures used in the sugar industry were used in the laboratory reactivation. A lower temperature and longer time of reactivation may prevent the destruction of the small pores of the carbon that occurred (as shown by the reduced iodine number). These fine pores may be relatively more important for sewage treatment than for sugar syrup decolorization. There was a gradual buildup in the carbon of "ash" that may have plugged the fine pores of the carbon. Acid-washing the carbon to remove the ash may prevent the loss in activity.

Flocculation And Settling Prior To Carbon Adsorption

Various dosages of alum ranging from 50 to 1,000 milligrams per liter were added to the waste-water samples to determine the lowest weight necessary to produce a clear solution. No significant differences in clarity or color, however, were apparent by visual observation of either the settled or filtered waste water over this range of flocculant. To assure maximum effect, therefore, a large dose of alum was used in subsequent tests. Data for a sample of secondary effluent of about normal COD and ABS concentrations are plotted in Figures 14 and 15. Both SGL and MWT carbons were used in the isotherm studies. The alum treatment of this sample resulted in an ABS reduction of 14 percent and a COD reduction of 36 percent. SGL carbon exhibited a higher capacity for both ABS and COD removal than did MWT carbon. Alum treatment increased the capacity of SGL carbon for COD from 37 to 73 percent according to the extrapolated equilibrium conditions at initial concentration. This is a highly significant increase. Furthermore, with the alum-treated effluent, carbon reduced the COD remaining in solution to much lower levels than those achieved with similar order carbon dosages in unflocculated effluent. Thus, indications are that alum flocculation is capable of removing materials that resist adsorption in a granular carbon column. The alum treatment increased the capacity of SGL carbon for ABS in this effluent from 7.2 to 8.1 percent.

Similar adsorption isotherms were developed for a second sample of secondary effluent that had a COD concentration much lower than normal. The results, plotted in Figures 16 and 17, show a similar but reduced effect of flocculation.

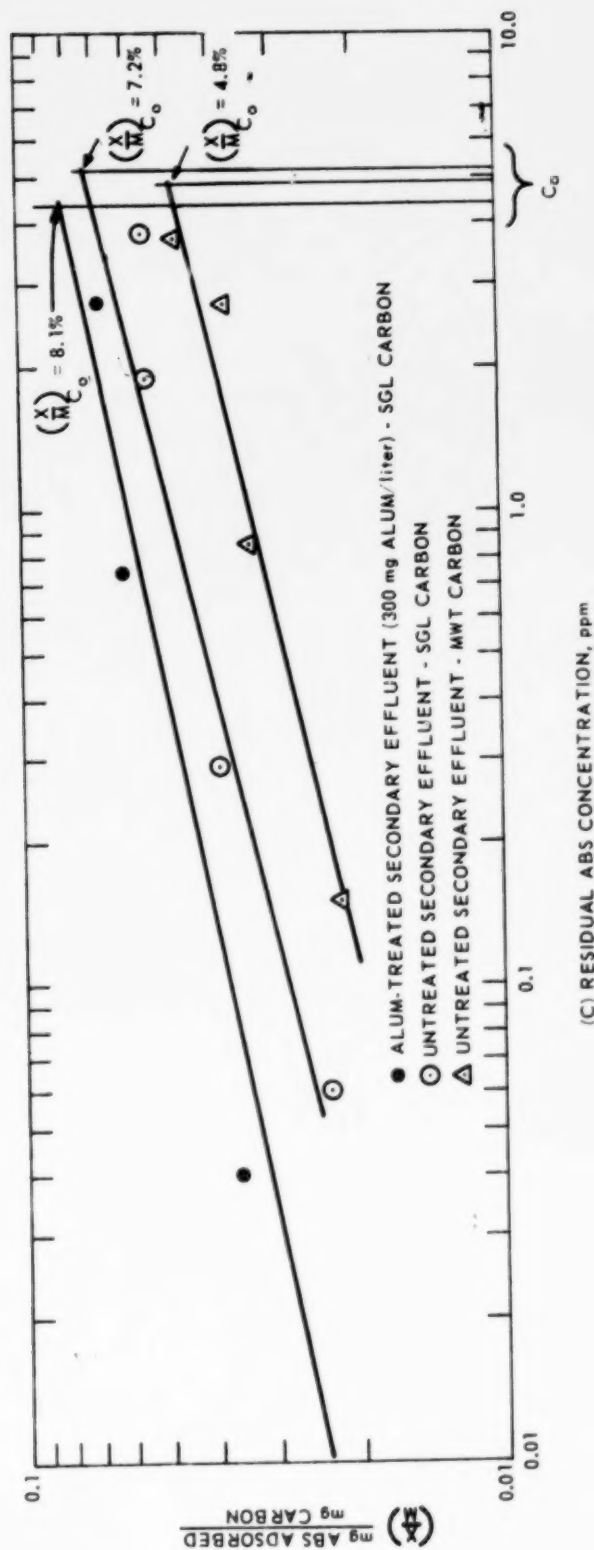


Figure 14. ABS isotherms for untreated and alum-treated secondary waste-water effluent (COD-concentration, 61.4 ppm).

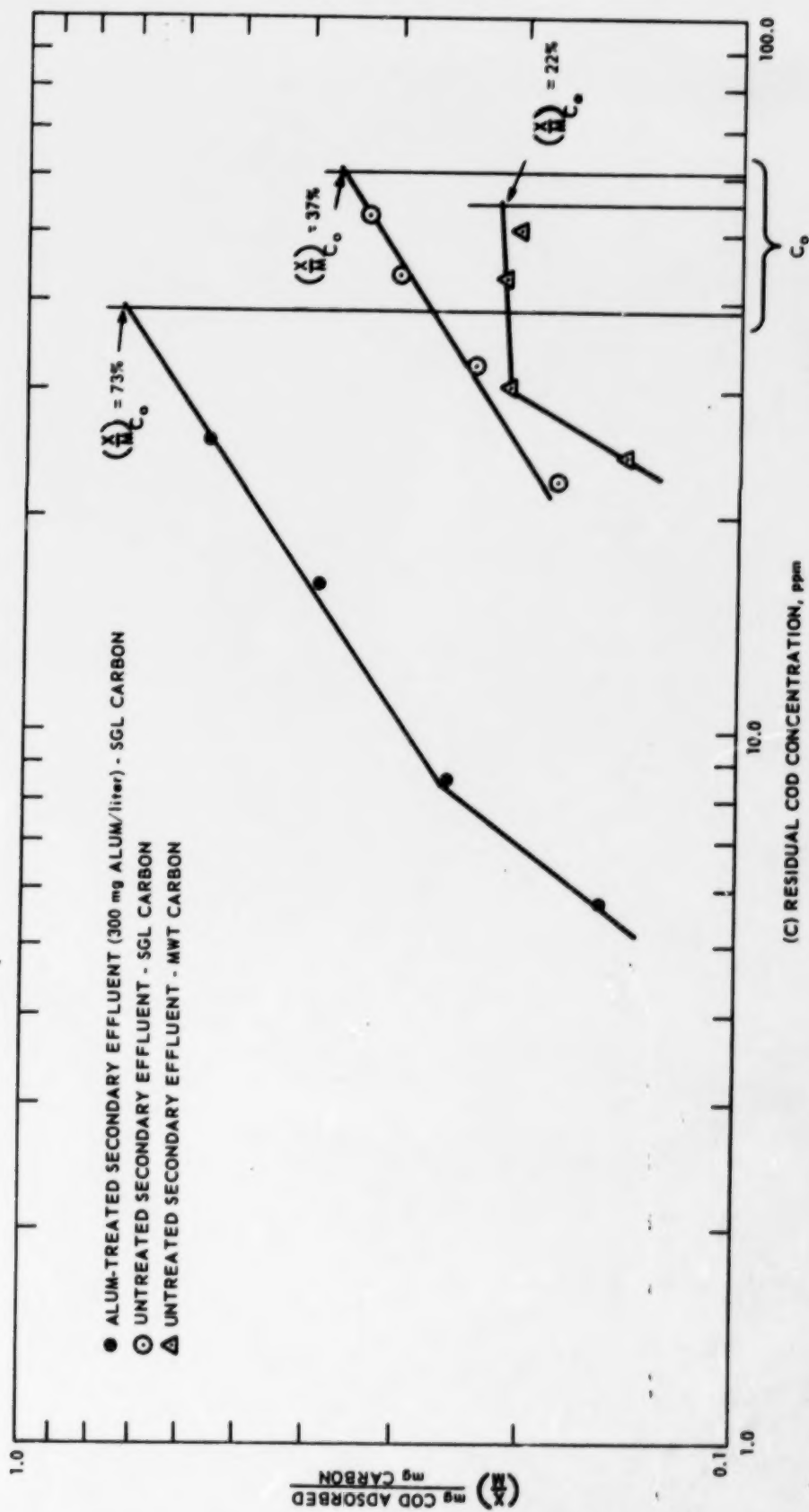


Figure 15. COD isotherms for untreated and alum-treated secondary waste-water effluent (COD concentration, 61.4 ppm).

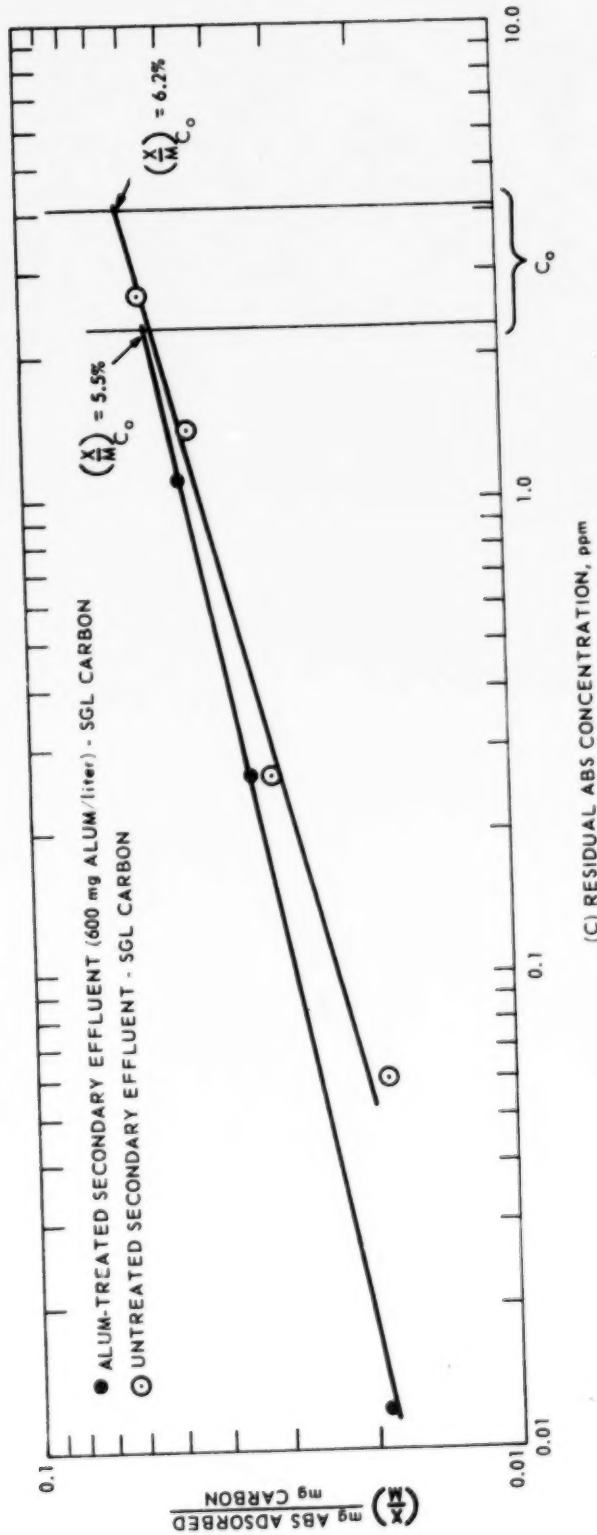


Figure 16. ABS isotherms for untreated and alum-treated secondary waste-water effluent
(COD concentration, 23.8 ppm).

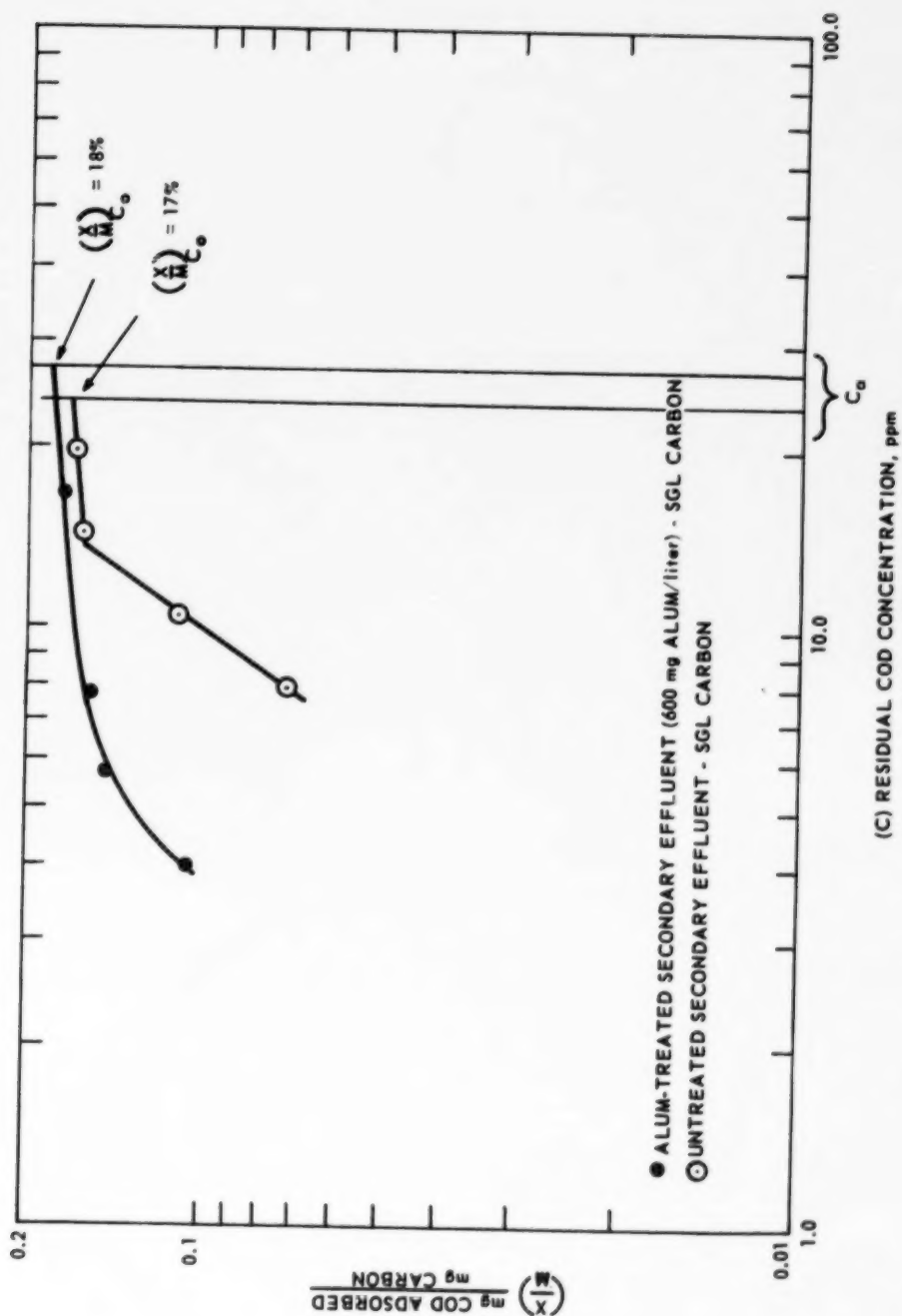


Figure 17. COD isotherms for untreated and alum-treated secondary waste-water effluent (COD concentration, 23.8 ppm).

REFERENCES

1. Joyce, R. S. and Sukenik, V. A., Feasibility of Granular, Activated-Carbon Adsorption for Waste-Water Renovation. PHS Publ. No. 999-WP-12. 1964. 32 pp.
2. Van Hall, C. E., Safrunko, J., and Stenger, V. A., Rapid Method for the Determination of Organic Substances in Aqueous Solutions. Anal. Chem. 35, 315. 1963.

APPENDIX

ADVANCED WASTE TREATMENT RESEARCH PUBLICATIONS

Although overall guidance of AWTR research projects is provided by the AWTR Program, the results obtained, opinions expressed, and conclusions reached by the contractors are theirs and are not necessarily endorsed by the Department of Health, Education, and Welfare. Except for editorial review and abridgments as necessary, these reports appear as received from the contractors.

		Report Number
AWTR-1	Summary Report, June 1960 - December 1961	W62-9
AWTR-2	Preliminary Appraisal of Advanced Waste Treatment Processes	W62-24
AWTR-3	Ultimate Disposal of Advanced-Treatment Waste	999-WP-3
	Part 1. Wet Oxidation	
	Part 2. Incineration	
AWTR-4	Waste-Water Renovation	999-WP-4
	Part 1. A Design Study of Freezing and Gas Hydrate Formation	
	Part 2. Feasibility Tests of Freezing	
AWTR-5	Contaminant Removal from Sewage Plant Effluents by Foaming	999-WP-5
AWTR-6	Cost of Purifying Municipal Waste Waters by Distillation	999-WP-6
AWTR-7	Advanced Waste Treatment by Distillation	999-WP-9

		Report Number
AWTR-8	Ultimate Disposal of Advanced- Treatment Waste	999-WP-10
	Part 1. Injection	
	Part 2. Placement in Underground Cavities	
	Part 3. Spreading	
AWTR-9	Adsorption of Biochemically Resistant Materials from Solution. 1.	999-WP-11
AWTR-10	Feasibility of Granular, Activated-Carbon Adsorption for Waste-Water Renovation	999-WP-12
AWTR-11	Evaluation of the Use of Activated Carbon and Chemical Regenerants in Treatment of Waste Water	999-WP-13
AWTR-12	Evaluation of Various Adsorbents and Coagulants for Waste-Water Renovation	999-WP-14
AWTR-13	Electrochemical Treatment of Municipal Waste Water	999-WP-19
AWTR-14	Summary Report: The Advanced Waste Treatment Research Program. January 1962 through June 1964	999-WP-24
AWTR-15	Feasibility of Granular, Activated-Carbon Adsorption for Waste-Water Renovation. 2.	999-WP-28